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PLATINUM
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COMMUNICATION

HABITAT SUITABILITY MODELING OF ASIAN ELEPHANT *ELEPHAS MAXIMUS* (MAMMALIA: PROBOSCIDEA: ELEPHANTIDAE) IN PARSA NATIONAL PARK, NEPAL AND ITS BUFFER ZONE

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Abstract: Asian Elephants *Elephas maximus* in Nepal are known to have habitats and movement corridors in Parsa National Park (PNP) and its buffer zone (BZ), located east of Chitwan National Park. A study was conducted in this area to assess the suitability of PNP and BZ as elephant use areas, and to determine factors relevant to the presence of elephants in PNP. Field measurements were carried out in 67 plots for vegetation analysis. Boosted Regression Tree (BRT) analysis was used to examine the relationship of habitat suitability and variables including topography (slope, aspect, altitude), climate (precipitation, temperature), habitat preference, ground cover and crown cover. The results indicate that elephant habitat suitability is mainly determined by the dominant plant species, temperature, altitude, habitat preference and precipitation. Slope, ground cover, crown cover and substrate have lesser effects. Elephants were recorded up to 400m in the northeast and southeast aspects of the study area. Most suitable habitats were low slope forest dominated by *Acacia catechu* and *Myrsine semicerate* that received 300mm annual precipitation. The model emphasizes environmental suitability, and contributes to knowledge for conservation of elephants in PNP and BZ by delineating sites that require specific planning and management.

Keywords: Boosted Regression Tree, corridor, elephant habitat suitability, important value index, vegetation.

Nepali Abstract: नेपालमा पाइने जङ्गली हात्तीको वासस्थान र क्रियाकलाप विशेषत चितवन राष्ट्रिय निकुन्जको पुर्वी क्षेत्रमा पर्ने पर्सा राष्ट्रिय निकुन्ज, यसको मध्यवर्ती क्षेत्रमा रहेको छ। यस अनुसन्धानले जङ्गली हात्तीको वासस्थानको उपयुक्तता, हात्तीले प्रयोग गर्ने क्षेत्र र हात्तीको उपस्थितीका कारकको बारेमा अध्ययन गरेको छ। स्थलगत रुपमा ६७ वटा प्लटको स्थापना गरी उक्त प्लटभित्र रहेका वनस्पतीहरुको विश्लेषण गरिएको थियो। बुस्टेड रिग्रेसन ट्री विधि लागू गरेर हात्तीको वासस्थान उपयुक्तता र कारकहरु जसमा स्तलाकृति (उचाइ, भिरालो, मोहडा), जलवायु (वर्षा, तापक्रम), वासस्थान प्राथमिकता, जमीन आवरण, छत्र आवरण जस्ता विभिन्न कारकहरुको अध्ययन गरिएको थियो। अध्ययनको परिणामले हात्तीको वासस्थान मुख्यतया प्रमुख वनस्पती प्रजाती, तापक्रम, उचाइ, वासस्थान प्राथमिकता र वर्षा निर्धारण गर्छ भनेर जनाएको छ। भिरालोपन, जमीन आवरण, छत्र आवरण र अरु कारकहरुले हात्तीको बासस्थान निधारर्णमा कम असर गर्ने देखियो। अध्ययन गरिएको क्षेत्रबाट ४०० मि. उत्तरपुर्वी र दक्षिणपुर्वी मोहडासम्म हात्ती सकृय रहेको पाइयो। न्युन भिरालोपन भएका खयर (*Acacia catechu*) र कालीकाठ (*Myrsine semicerate*) प्रजातीले ढाकेको वनक्षेत्र जहा वार्षिक वर्षादर ३०० मिमि रहन्छ त्यस्तो क्षेत्र सबैभन्दा उपयुक्त बासस्थानको रुपमा पाइएको छ। उल्लेखित क्षेत्र तोकेर यस मोडलिंगले हात्तीको बासस्थानको वातावरणिय उपयुक्तता र पर्सा र यसको मध्यवर्ती क्षेत्रमा हात्तीको संरक्षणको लागी ज्ञान प्रदान गर्नतर्फ जोड दिएको छ, जुन कुरा हात्तीको वासस्थान व्यवस्थापन र योजनामा आवश्यक पर्छ।

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INTRODUCTION

The Asian Elephant was recognized as an endangered species in 1975 after its inclusion in Appendix I of CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) (Bisht 2002) and listed as "Endangered" on the IUCN Red List of Threatened Species (IUCN 2017). These elephants are found in a variety of habitats that include grasslands, tropical evergreen, moist deciduous, dry deciduous and dry thorn forests, as well as secondary forest, scrublands, and cultivated areas (Sukumar 2003). Armbruster & Lande (1993) stated that human encroachment of natural habitats is one of the most critical issues facing elephant conservation. In Asia, elephants have lost extensive habitat areas, and as a result, conflicts with people have increased (Santiapillai 1997).

In Nepal, elephants are distributed throughout the lowland Terai in four isolated populations ranging over 10,982km^2 of forest habitat (DNPWC 2008). The estimated number of resident wild elephants in Nepal is between 107 and 145 (DNPWC 2008; Pradhan et al. 2011). The eastern population has 7–15 resident animals and 100 migratory animals from India. In central Nepal, 20–25 elephants reside primarily in Parsa National Park (PNP) and Chitwan National Park (CNP). The western and far western populations consist of 60–80, and 15–20, wild elephants respectively (DNPWC 2008; Pradhan et al. 2011).

Habitat conservation is an important aspect of wildlife conservation, and habitat suitability analysis is an essential aspect of management of wild animals such as elephants. Habitat suitability modeling can predict the quality and suitability of habitats for given species based on predictor variables such as topography (aspect, slope, altitude), climate (temperature, precipitation) and other biotic and abiotic factors. Different methods of modeling are used to determine suitable habitats for elephants. The boosted regression trees (BRT) method is an ensemble tree-based species distribution modelling technique that iteratively grows small/ simple trees based on the residuals from all previous trees (Elith et al. 2008). BRT has proven useful for working with large datasets of environmental variables and observations (Elith et al. 2008). For example it has been used to identify determinants of above ground biomass (Adhikari et al. 2017) and fish species distribution (Elith et al. 2008; Trigal & Degerman 2015). BRT and geographic information have also proven to be effective in the assessment of habitat quality.

The present study aims: 1) to assess the suitable habitat of elephants, and 2) to determine which explanatory variables better explain elephant presence in PNP and buffer zone. This study has assessed habitat suitability in order to provide insights towards better management of elephant populations.

METHODS AND MATERIALS

Study area

The study was conducted in Parsa National Park (PNP) and its buffer zone (BZ), located in the sub-tropical zone of the southern part of Nepal. It has an area of 627km^2. In 1984, PNP was established to preserve the habitat of natural populations of Asian Elephant *Elephas maximus*, Tiger *Panthera tigris*, and Gaur *Bos gaurus* (Rimal et al. 2018). The BZ of PNP was declared in 2005, which covers an area of 285.17km^2 encompassing three districts and 11 village development committees (VDC) (Figure 1). The region experiences four different seasons: summer (April–June), rainy/monsoon (July–September), winter (October–December), and spring (January–March).

The forests of PNP consist of tropical and subtropical tree species. Sal *Shorea robusta* forests compose about 90% of the park's vegetation. The riverine forests are found along the banks of rivers entailing species like Sisso *Dalbergia sisoo*, Silk Cotton Tree *Bombax ceiba*, and Khair *Acacia catechu*. Grass including Siru *Imperata cylindrica* and Kans *Saccharum spontaneum* are in the park. PNP and BZ support various endangered animal species including wild Asian Elephant, Royal Bengal Tiger *Panthera tigris*, and Sloth Bear *Melursus ursinus*. Mammals including Blue Bull *Boselaphus tragocamelus*, Sambar *Rusa unicolor*, Hog Deer *Axis porcinus*, Barking Deer *Indian muntjac*, Rhesus Macaque *Macaca mulatta*, and Palm Civet *Paradoxurus hermaphrodites* are also found in the park. Anthropogenic pressures like sand extraction, shifting cultivation and domestic cattle grazing are high in PNP and BZ (CHEC Nepal 2012).

Quantitative data collection

Field work was conducted during the morning hours of May–June 2017. In reconnaissance, the habitats preferred by elephants were identified in consultation with local people. Questions concerned areas where elephants were frequently sighted, places where indirect signs of elephants were found, and availability of water. Reconnaissance field visits were made with the help of elephant rides, on foot and by vehicle, and areas were allocated into blocks according to habitat types. Sample plot centers were positioned using hand-held Garmin

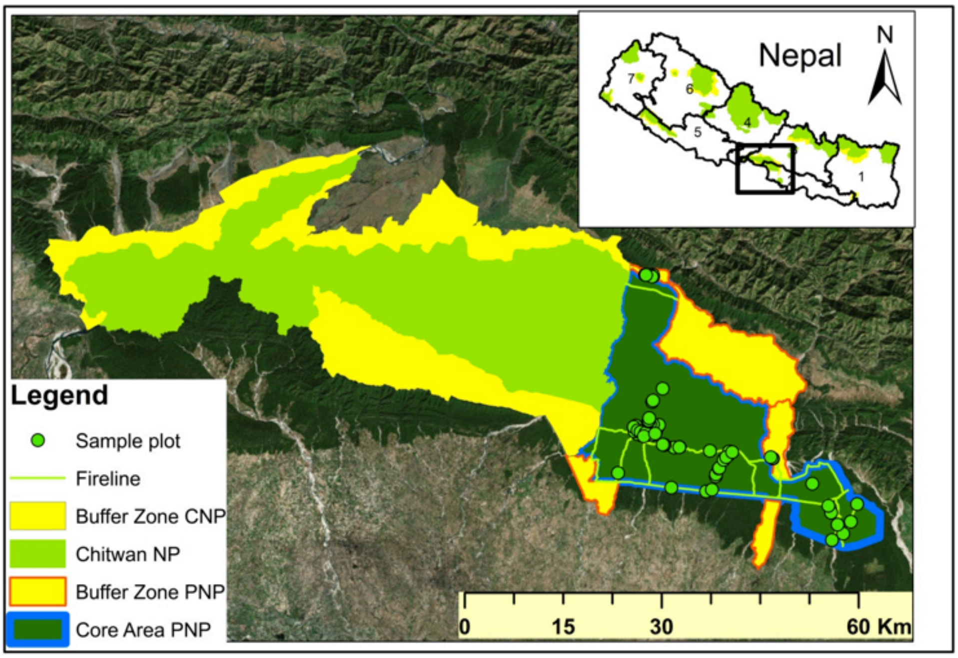

Figure 1. Location of the study area and sample plot distribution in Parsa National Park and buffer zone, Nepal.

global positioning system (GPS) with a 2–5 m accuracy.

Nested quadrats of different size were purposively assigned in the study area (Figure 2). Total 67 plots were assigned and used to assess the status of tree, pole and regeneration condition. Quadrats of 10m × 10m were set in the study area to calculate the intensity for tree species. All plant species within each quadrat were identified and counted. For trees, trunk diameter at breast height (DBH; 1.3m) and height was measured. Quadrats of 5m × 5m were allocated randomly for shrubs. Herbs and regeneration were recorded from nesting sampling of 1m × 1m quadrate within the 5m × 5m quadrate.

Tree diameter, height, dominant species, crown cover and ground cover were measured, poles and regeneration were counted and in cases of grasses, clumps were counted within each quadrat. Plant species were identified by a local para-taxonomist, field guide and also based on literature related to plant identification in Nepal (Rimal et al. 2018). Leaves of unidentified tree species were brought to the faculty of forestry at Agriculture and Forestry University (AFU) and were identified.

To assess the habitat, important value index (IVI) and prominence value (PV) of vegetation available in the habitat range is crucial. The vegetation data collected in the field were used to calculate IVI, density, relative density, frequency, and relative frequency of the tree species by using equations 1–8 explained in Greig-Smith (1983). The IVI of a species signifies its dominance and

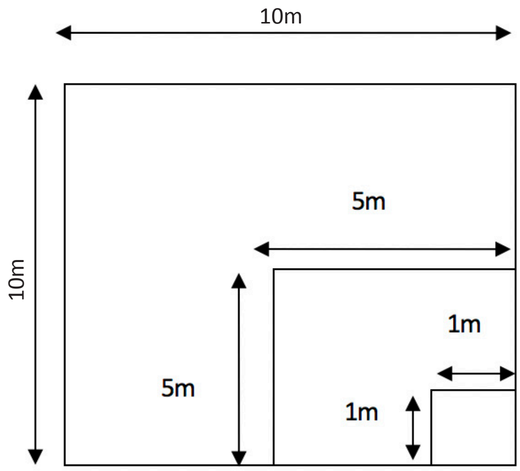

Figure 2. The layout of the quadrate used to assess the status of tree, pole and regeneration condition.

ecological success, its good power of regeneration and greater amplitude. The IVI was calculated by using three measures including relative frequency, relative density, and relative dominance. Vegetation data were calculated following the broad principle described by Mishra (1968) and Mueller-Dombois & Elienberg (1974). Basal area helps to determine the dominance and nature of the community and it refers to the actual ground covered by the stems. Density is generally used for large plants that have discrete individuals (Zobel et al. 1987). Frequency and relative frequency give an index on the spatial distribution of a species (Krebs 1978). To calculate the prominence value, the percentage cover of each species is estimated in each quadrate and recorded in classes as follows, for high coverage = > 50%, medium= 26–50% and low = 0–25%. Prominence value is used to calculate the availability of plants in the research sites (Jnawali 1995).

1. Density of species = (Total number of individuals of a species) / (Total number of quadrats sampled × area of a quadrate)

2. Relative density of species (RD) = (Total individuals of species) / (Total individual of all species)

3. Frequency of species = Number of plots in which a particular species occurs / Total number of plots sampled × 100

4. Relative frequency of species (RF) = Frequency value of a species / Total frequency of all species × 100

5. Relative dominance of species = Total basal area of a species / Total basal area of all species × 100

6. Basal area = $\pi d^2/4$

7. Important value index (IVI) = Relative density + Relative frequency + Relative dominance

8. PVX = MX ($\sqrt{FX}$)

(where, d = diameter at breast height (1.3 m) of tree, PVX = prominence value of species X; MX = mean percentage cover of species X; FX = Frequency of occurrence of species X)

Explanatory variables for modeling of habitat suitability distribution

A range of explanatory variables was derived from geospatial data sets for modeling habitat suitability. Table 1 presents the complete list of variables. The slope, aspects, and altitude were derived from the Japan Aerospace Exploration Agency (JAXA) digital elevation model (dem). Precipitation and temperature were downloaded from WorldClim data. Field measurements, dominant species, habitat preference, segment type, crown and ground cover and substrate conditions were derived. All topographic, climatic, and land use data available for the study area were resampled to 30m resolution and UTM 45N, WGS 84 projection system. For each absence and presence of GPS location, these variables were extracted. The correlation co-efficient between the explanatory variables and presence-absence data of elephant is shown in Appendix 1.

Statistical analysis

Boosted regression tree (BRT) (Elith et al. 2008) was used for examining the habitat preference area for elephant. BRT handles different types of predictor variables and accommodates missing data (Elith et al. 2008). Besides these, there is no need for prior data transformation or elimination of outliers. This is an advanced form of regression methods, which consists of two component—regression trees and boosting. BRT analysis was done using the 'dismo' package in R. The Bernoulli error distribution was used. Furthermore, the minimum predictive error was achieved when using a learning rate of 0.001, tree complexity (interaction depth) of 5, bag fraction of 0.75 and tolerance method "fixed". All predictor variables were used as BRT can handle multi-collinearity among variables.

RESULTS

Habitat assessment

IVI was calculated to find out the dominant tree species (Appendix 2) and prominence value was observed in the case of shrubs and herbs (Appendix 3 & 4). We calculated the species diversity of the study area for trees. Fifty-seven species were present in the quadrates; among them, 10 tree species were the dominant tree species present in the study area. In the study area, Sal (IVI–50.7753) was found most dominant and *Careya arborea* (IVI–5.2802) as least dominant. The species including *Mallotus philipinensis, Dillenia pentagaina, and Careya arborea* have the highest IVI among all, and they are the most preferred species of the elephant.

To determine the preferred habitat used by elephant, we calculated the PV of shrubs and herbs. Among 40 species, each of shrubs and herbs was present in the study area. Among the shrub species, *Eupatorium spp.* (PV–306.25) was the most abundant species and *Bauhinia vahilli* (PV–53.07) was the least abundant. Among the herb species, *Imperata cylindrica* (PV–317.66) was the most abundant and *Piper longum* (PV–29.48) the least abundant. The shrub species including *Eupatorium odoratum, Leea macrophylla, and Cleroden dronviscosum* and herb species including *Imperata cylindrica, Saccharum spontaneum,* and *Fritillaria camschatcensis* have the highest PV among all species found in the study area as well as, they are the most preferred species of the elephant in the study area.

Habitat suitability

The total deviance explained by the BRT model was 0.16. The correlation between different variables, including presence-absence, altitude, land cover of the plot, segment type, substrate condition, dominant species, ground cover, crown cover, habitat preference,

Table 1. Predictor variables used to model the habitat of Elephant.

Predictor variables	Format (Source)	Description
Temperature (× 10 °C) (1km × 1km)	Raster (WorldClim) 1*	The temperature of June was used
Precipitation (mm) (1km × 1km)	Raster (WorldClim) 1*	Precipitation of June was used
Slope (°) (30m × 30m)	Raster (Jaxa DEM) 2*	
Aspect (30m × 30m)	Raster (Jaxa DEM) 2*	
Altitude (30m × 30m)	Raster (Jaxa DEM) 2*	
Habitat preference	Field measurement	Species preferred by elephant, including *Mallotus philipinensis, Imperata cylindrica, Dillenia pentagina, Saccharum spontaneum, Careya arborea*, and *Pennisetum purpureum*
Dominant Species	Field measurement	Area dominated by species like *Acacia catechu* (AcC), *Bombax ceiba* (BoC), *Dillenia pentagaina (*DiP), *Albizzia procera (*AlP), *Lagerstroemia parviflora* (LaP), *Terminalia chebula* (TeC), *Trewia nudifolia* (TrN), and *Myrsine semicerata* (MyS)
Segment type	Field measurement	Divides the area into the segment by fire line, foot trail, pond, river, and railway
Crown and ground cover	Field measurement	Cover (%) of forest crown and ground
Substrate condition	Field measurement	The condition of the soil, including hard soil, soft soil, and leaf litter

1*—www.worldclim.org | 2*—www.global.jaxa.jp/press/2015/05/20150518_daichi.html.

precipitation, temperature, slope, and aspect is shown in Appendix 1. The relative influence of each predictor variables is shown in Figure 3. Each predictor variable has different relative contributions for the BRT model. Dominant species, temperature, and altitude have higher relative influence, whereas ground cover, crown cover and substrate condition have a lower relative influence.

Prioritized dependence plots visualize the effect of a single variable on the model response, holding all other variables constant. Model results vary the most with dominant species as seen in the first left plot (Figure 3). Dominant species (34%), temperature (15.3%), altitude (12.4%), habitat preference (11.1%) and precipitation (8.8 %) have the highest relative influence percentage and play a crucial role in the elephant distribution based on these plots. For more details on how they were calculated and model parameters used, see Sharma (2017).

On the basis of partial dependence plots, the elephant was more available at the altitude of 250–350 m with precipitation 310mm. The suitable habitat for the elephant was at the temperature of 28.5°C, a slope of 0–5° and in the northeastern and southeastern regions. Dominant species shows that *Acacia catechu* (AcC) and *Myrsine semicerata* (MyS) forest are more suitable for the elephant. Species including *Dillenia pentagaina* (DiP), *Saccharum spontaneum* (SaS), and *Pennnisetum purpureum* (PeP) are the most preferable species of the elephant. Elephants dwelled in forest dominated by *Mallotus philipinensis* followed by *Syzigiym cumini*. Thus areas having these species were the most suitable habitats.

The weighted mean of discrete data was not available, whereas the weighted mean of continuous data was altitude (264m), precipitation (310mm), temperature (28.6 °C), slope (5.6°) and aspect (190°). Elephants were found mostly around the fire line and river, at an altitude of 150–350 m with temperature around 28.6 °C, crown cover 40–70 and slope below 0–5° (Figure 4).

The correlation between elephant presence-absence and temperature is 0.24, that implies a slight positive relationship between them, the elephant is mostly found in increasing temperature (Appendix 1). Whereas there is almost no linear association between presence-absence, and slope, dominant species, land cover of the plot, crown cover and ground cover. The relationship of altitude with temperature is negative, i.e., 0.84, the temperature of the area increases with a decrease in altitude and vice versa.

The elephant distribution prediction map based on altitude, slope, aspect, precipitation, and temperature only using boosted regression tree model is presented in Appendix 5. Other predictor variables were based specifically on field data and their extrapolation to spatial scale was not possible.

DISCUSSION

The elephant population in Nepal is restricted to the Terai and Siwalik regions, where there have been large-scale conversion of forest and expansion of agricultural lands (Koirala et al. 2015). This has resulted

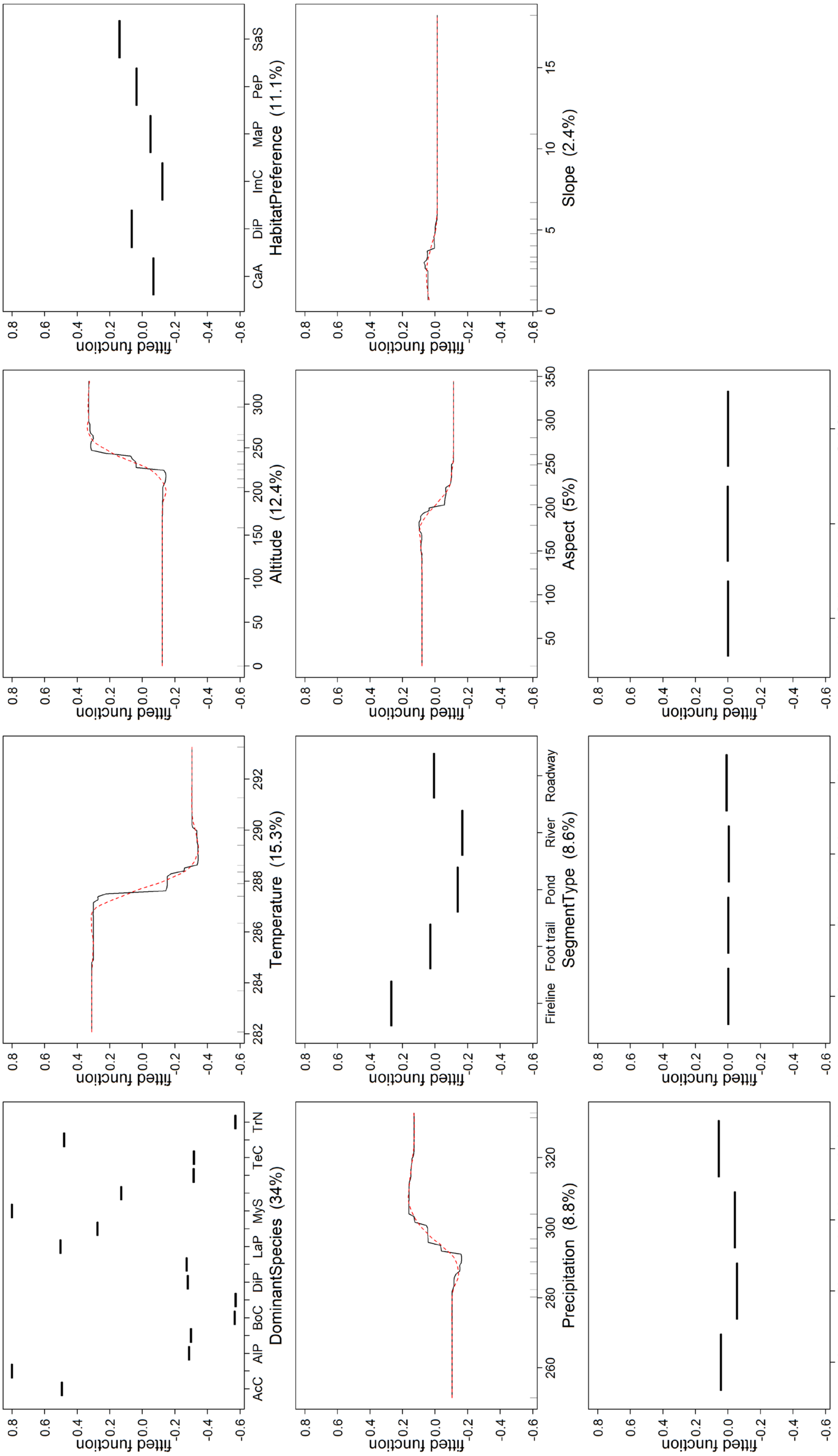

Figure 3. Single-variable partial dependence plots and smoothed response curves for the predictor variables, where Y-axis is the fitted function for the response variable (elephant). The relative influence is shown in parantheses.

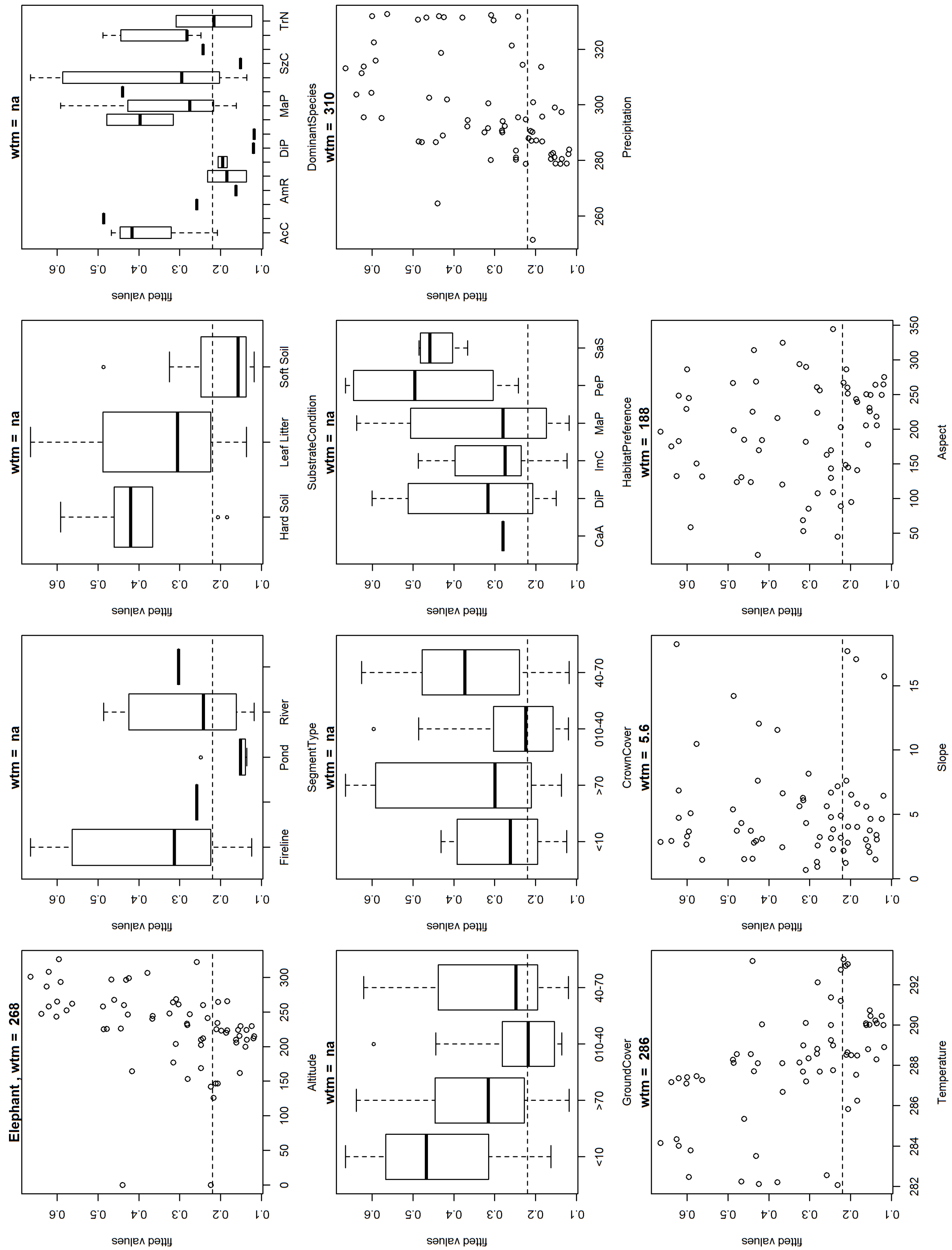

Figure 4. The weighted mean of all predictor variables.

in negative human-elephant interactions in many parts of Nepal. Movement of elephants outside the national park and wildlife reserve could have been the result of unsuitable habitat, reduced supply of food and water, and encroachment by human beings. Assessing habitat suitability of elephants assists in the preparation of sustainable management plans. PNP and BZ has been the habitat of elephant for long time, but habitat suitability studies are rare in this area. This research examines habitat suitability of the elephant in PNP and BZ based on different variables including dominant species, temperature, altitude, habitat preference, precipitation, segment type, aspect, slope, ground cover, crown cover and substrate condition.

Based on the BRT model, PNP and BZ are suitable habitats for elephants. We witnessed the outcome of parameters as per the physical, biological and climatic features of the area like slope, aspect, altitude, precipitation, temperature, habitat preference, crown cover and ground cover. The result shown by Koirala et al. (2016) posits that species like *Spatholobus parviflorus*, *Saccharum spontaneum*, *Shorea robusta*, *Mallotus phillippensis*, *Garuga pinnata*, *Litsea monopetala* contributed the highest proportion of diet for an elephant in the PNP. In consent with our result, similar species of trees, shrubs, and herbs have the highest IVI and PV and distributed in the lower part of the area. This result concludes that the study area is the most suitable for elephant to dwell. Our study revealed that the habitat is suitable in the Northeast and Southeast region of the study area, which is similar to the result of Shamsuddoha & Aziz (2015).

Rood et al. (2010) studies have found that the elephant's habitat use in a tropical forest is depicted by areas of high forest cover. Our analysis, however, found no marked relationship between ground cover, crown cover, and presence of elephants. Our findings revealed that in the study area, slope 0–5° and altitude 400m is suitable for elephants which are almost similar to the result of Areendran et al. (2011). In accordance with the studies of Douglas et al. (2006), Lin et al. (2008) and Ochieng (2015), suitable habitat for elephants was found to be limited by augmentation of both altitude and slope. There is no abundance of elephants' presence sign with the increment of the altitude and slope in PNP. In order to preserve their energy needs, Ntumii et al. (2005) mention that elephants avoid the height and steeply sloped area.

Variability in results might have occurred due to the differences in sampling methods, variance in forest condition, composition, and sampling area, etc. The research outcome was concluded based on only one season field work; however, taking all the results of four seasons might produce more effective result. Data of precipitation and temperature were extracted from Worldclim; the data taken from the nearest metrological station of Samara could be better with more accuracy. The outcomes from this study, linked to slope, and elevation are valid for PNP only, and cannot be generalized to the habitat of an elephant in other countries. Further research should focus on creating map of elephant distribution, habitat suitability, and threats to elephant from invasive species.

CONCLUSION

BRT was applied to assess elephant habitat suitability in PNP. In this study, we analyzed the distribution of elephant using a combination of biotic and abiotic environmental variables, including the topographic and climatic factors. The model emphasizes on environmental suitability and contributes to knowledge for conservation of elephant in PNP. It provides a basis for habitat analysis. Elephants were recorded up to 400m and in northeastern and southeastern aspects. Its presence could not be related to forest cover and substrate condition. The result from the modeling may become useful to plan and delineate areas for management of elephant. It presents scope to minimize HEC through precautionary measures.

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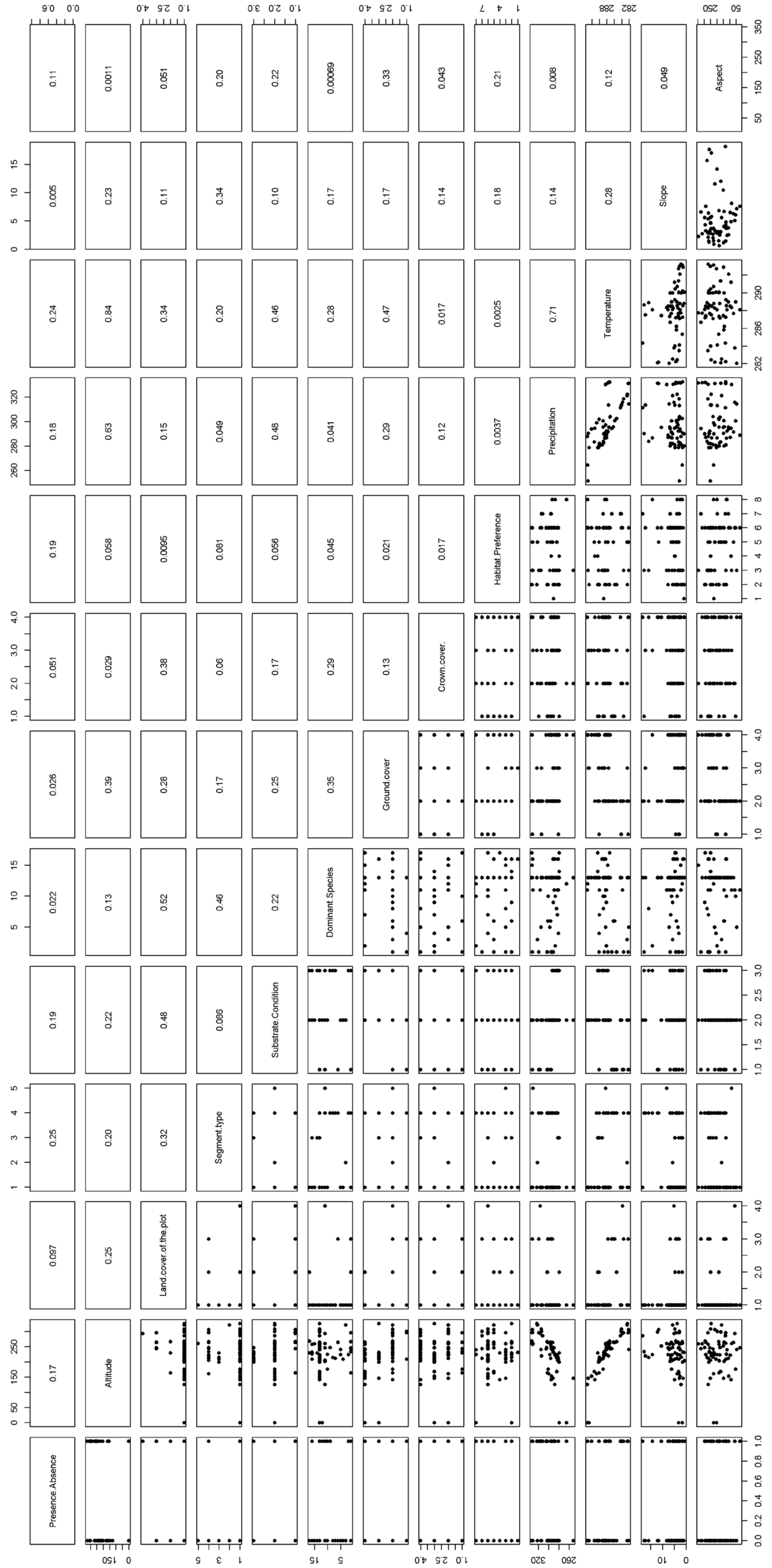
Author contribution: PS planned and conducted this research, HA and ST supervised this research. HA, PS and ST together worked on manuscript. HA and PS collected RS and GIS data. PS, RB and ST collected field data. AKR supervised PS during field data collection.



Appendix 1. Pearson correlation between different predictor variables and their scatter plots.

Appendix 2. Important Value Index (IVI) of dominance tree species

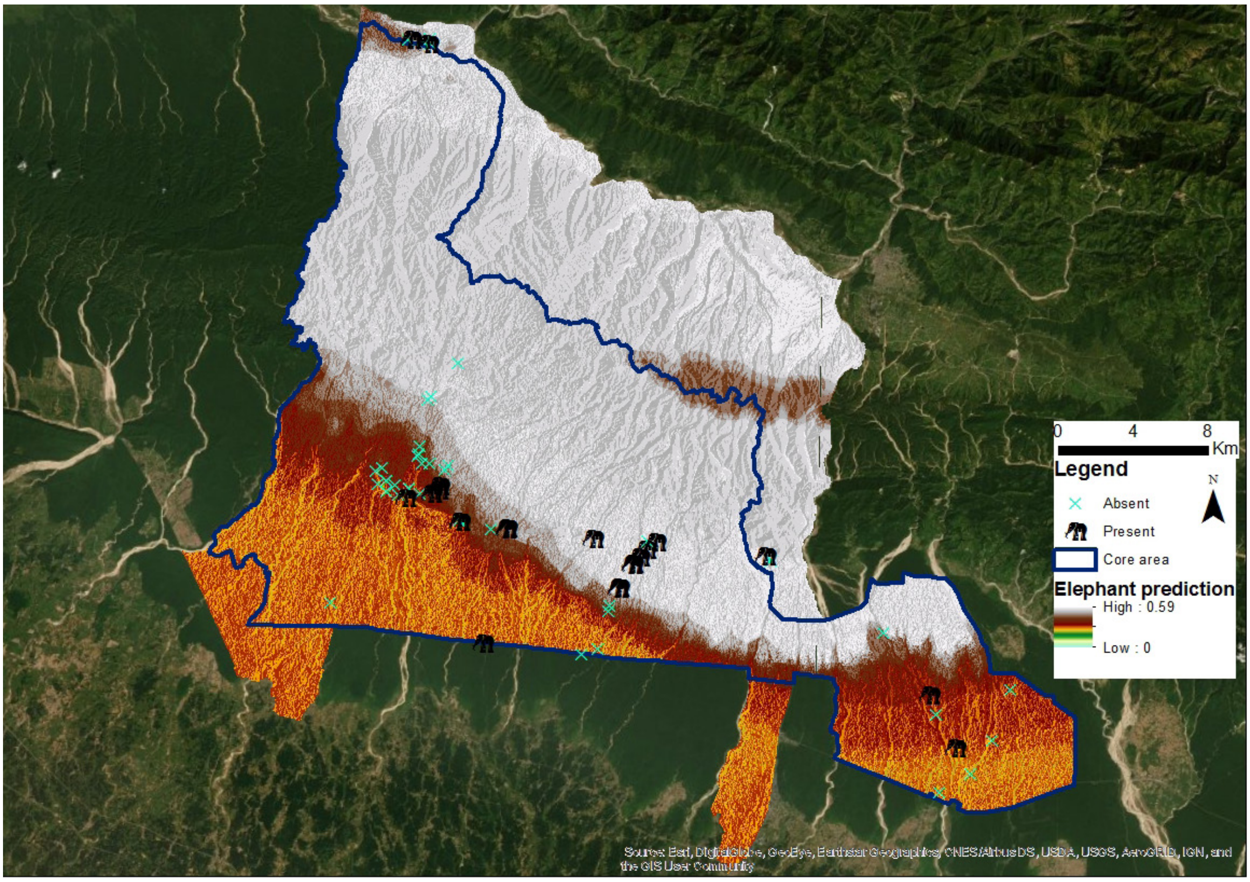
Scientific name	Local name	Relative frequency	Relative density	Relative dominance %	Important value index (IVI)
Shorea robusta	Sal	13.36	0.27	37.14	50.77
Mallotus philipinensis	Sindure	6.45	0.14	10.60	17.20
Terminalia tomentosa	Asna	4.60	0.04	8.22	12.87
Acacia catechu	Khair	4.60	0.11	5.57	10.29
Lagestromia parviflora	Bot dhayero	6.91	0.05	3.44	10.41
Dillenia pentagaina	Tatari	6.45	0.05	3.73	10.23
Adina cordifolia	Haldu	3.68	0.02	3.44	7.14
Garuga piñata	Dabdabe	5.06	0.03	1.97	7.08
Albigia procera	Setosiris	2.76	0.01	3.10	5.88
Careya arborea	Kumbe	2.76	0.01	2.50	5.28

Appendix 3. Prominence value of shrubs in the study area.

Scientific name	Local name	Number of individuals	Frequency	Mean cover of individual species (M_x)	Prominence value (PV_x)
Eupatorium odoratum	Setobanmara	188	50.72	43	306.25
Leea macrophylla	Galini	213	50.72	38	270.64
Clerodendron viscosum	Bhati	248	33.33	25	144.33
Murraya koenigii	Curry leaf	72	26.08	20	102.15
Fritillaria spp.	Thulobandhan	19	5.79	30	72.23
Lantana camera	Lantana	14	4.34	30	62.55
Asparagus racemosus	Kurilo	34	18.84	14	60.76
Agiratus conyzoides	Gande	111	5.79	25	60.19
Parthenium spp.	Parthenium	517	5.79	24	57.78
Bauhinia vahlli	Bhorla	20	8.69	18	53.07

Appendix 4. Prominence value of herbs in the study area.

Scientific name	Local name	Number of individuals	Frequency	Mean cover of individual species (M_x)	Prominence value (PV_x)
Imperata cylindrica	Siru	3516	42.02	49	**317.66**
Saccharum spontaneum	Kans	970	13.04	32	115.57
Fritillaria camschatcensis	Ban dhan	1035	18.84	20	86.81
Hemalthriya compressa	Ghodeydubo	699	10.14	25	79.62
Cynodon dactylon	Dubo	634	7.24	29	78.06
Digitarea spp.	Chitrebanso	382	10.14	23	73.25
Pennisetum purpureum	Elephant grass	163	4.34	22	45.87
Barlaria cristata	Kuro	151	7.24	16	43.07
Dendrobium spp.	Orchid	27	7.24	11	29.61
Piper longum	Pipla	18	8.69	10	**29.48**



Appendix 5. Elephant distribution prediction based on altitude, slope, aspect, precipitation, and temperature only using boosted regression tree model. Other predictor variables were based on field data and not available at the wall-to-wall spatial scale.

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